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STUDIES IN THE SO-CALLED PORPHYRITIC GNEISS OF NEW HAMPSHIRE. II.

Contact Metamorphism.— The endomorphic changes wrought by the granite intrusions are relatively slight. Thus the biotite-gneiss and hornblende-gneiss southwest of Lake Wakawan have the same mineralogical composition at the contact as they have a quarter of a mile away from it along the strike. On Spindle Point, gneisses of like nature show the only exomorphic change discovered throughout the whole terrane of the Lake Winnipiseogee gneiss. Yet even this is a doubtful case, since the only evidence is the presence of some sillimanite needles and a few garnets in the schist near the granite. Again, the interbedded biotite-gneiss, muscovite-biotite-gneiss, and actinolite-gneiss, at the outlet of Little Squam Lake, are practically unaffected by the granite. The same is true of the large biotite-gneiss-inclusion on the north side of Beech Hill, as well as of the whole contact-line of the Montalban group.

The schists on Saddle Hill exhibit the best metamorphic belt which appears in the Winnipiseogee area. Specimens of the country-rock were taken at localities from one to eight hundred feet from the contact, and in all of them the country-rock proves to be a typical muscovite-biotite-schist with accessory sillimanite in long needles. Inside that zone toward the granite, however, a pronounced metamorphic aureole encloses phases of the terrane which represent important modifications of the schist. One of them, some eighty feet from the contact, is a hornfels largely made up of zoisite and andalusite (?) with quartz and magnetite. Another, four feet from the granite, is a compact mica-schist richly charged with garnets; while within five inches of the contact this garnetiferous schist has absorbed a large amount of orthoclase and plagioclase which seem to have been derived from the neighboring granite.

The Ashuelot area is even more nearly devoid of distinct zones of contact-alteration. Several suites of specimens were taken across the marginal belt of schists at several different localities, but in none of them was a definite alteration of mineral content observable, as one goes toward the igneous rock. While the Coös schists are highly garnetiferous at the contact, they are often just as metamorphic in habit a mile or more from the granite. Interlaminated actinolite-schists are abundant among the common mica-schists of the area. They show no change at the contact. The Bethlehem gneiss is often garnetiferous, and in some slides the garnets are seen to be larger and more idiomorphic near the granite than away from it. Apart from this fact, one would not suspect from an inspection of the marginal alterations that the porphyritic granite was once an igneous body intruded in these same rocks in a molten state.

Finally, it would be difficult to point to any particular part of the Main area as exhibiting metamorphic phases in the schistose country-rock of the porphyritic granite which could not have been produced before the granite was erupted. One hundred and fifty feet from the great Greenfield sheet a typical quartz-garnet-hornfels can be found, but from that rock to the granite one passes over the typical biotite-muscovite-schist of the region. The latter itself may be garnetiferous. It does not, however, differ from similar phases of the ferruginous rocks several miles from the contact. North of Henniker there outcrops another hornfels at a contact with a prophyritic granite apophysis and about 50 feet from the molar contact. It is a compact aggregate of quartz and garnet with a large admixture of a colorless pyroxene and a little accessory plagioclase and muscovite. Notwithstanding this kind of association, these and other examples cannot as yet with safety be considered as contact phases, nor do they afford positive evidence of an eruptive origin for the porphyritic granite.

The small amount of exomorphic change in the contact-belt is that which might be expected from the conditions of the eruptions. It is well known that, other things being equal, acidic igneous rocks are less likely to be altered by intrusive masses than are the more basic rocks. In the same way sedimentary rocks are in general more susceptible to contact metamorphism than the crystalline chists or than igneous rocks.[1] Pohlig noted important differential effects of the trachyte in the Siebengebirge. Fragments of gneiss enclosed in the eruptive rock were relatively unchanged as compared with inclusions of clay-slate in which andalusite and other metamorphic minerals were developed.[2] Lehmann has described granulite inclusions in the granite of Markersdorf which he found to be entirely unchanged by the granite.[3] No student of contact-belts needs, however, to be reminded that in them there is pronounced selective metamorphism depending upon the nature of the rocks invaded. Those which have advanced furthest in the direction of mineralogical stability will usually be the rocks which are least altered. If, then, there had been regional metamorphism of the country-rock before a given intrusion occurred, such terranes will tend to be without distinct zones of alteration. Such is the case with the New Hampshire rocks. In the sequel the chief evidence for this conclusion will be given, but we can anticipate somewhat by stating the fact that the same series of schists which are cut by the porphyritic granite are just as thoroughly crystalline many miles from the porphyritic granite as they are in its immediate vicinity. Moreover, they attained this crystalline character in the process of mountain-building and not by any kind of local thermo metamorphism induced by underlying areas of the porphyritic granite.[4] The eminent schistosity of these rocks was anterior to the granitic intrusion, and it is an effect concomitant with the recrystallization. Thus it was a series of terranes already regionally metamorphosed that were cut by the porphyritic granite. They had reached a state of approximate mineralogical equilibrium and but little rearrangement of the constituent elements was possible by mere contact action.

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[1] Cf. HUDLESTON, Address Pres. Geol. Soc., 1894; Q. J. Geol. Soc., p. 121.

[2] Tschermak's Mitth., 1880–1, p. 353.

[3] Untersuch. über die Entsteh., der altkryst. Schiefergesteine, 1884, p. 7.

[4] Cf. BARROW, Q. J. Geol. Soc., 1893, p. 352.

Moreover, at Fitzwilliam, where the inclusions of the neighboring biotite-gneiss are extremely well exposed, there does not seem to be the slightest change in the horses. Yet there can be no doubt that the porphyritic granite is here distinctly eruptive in the gneiss. In the same way, the ancient granitite described on the west and northwest of the village of Antrim has produced no material alteration in the composition of the schist inclusions, for in that feature they are identical with their parent terrane for several miles from the contact.

It seems reasonable, then, to conclude from the brief account of exomorphic contact-phenomena just given that they do not invalidate the argument for the porphyritic granite's being eruptive. It means that the conditions were not such as to permit of the development of the well-marked metamorphic aureoles which one might expect in invaded terranes composed of relatively unaltered rocks.

Endomorphic changes.— More often than not where the actual contact between the porphyrictic granite and the older formations appears, there is practically little change either in the composition or grain of the granite. This fact is characteristic of apophyses as well as of the main body. In the Winnipiseogee and Main areas particularly, the feldspar phenocrysts and their matrix are remarkably persistent in the size of individual minerals. The reader will remember that a broad band of the porphyritic granite with rare phenocrysts appears on the western side of the Ashuelot area, and again that, on the eastern side, there is evidence of fine-graining in the Bethlehem gneiss-contact which can hardly be explained except as belonging to a chilled phase of the igneous rock. It is true, however, that this phenomenon is, on the whole, rather the exception than the rule in the different areas. We cannot but think that the invaded schists must have been at a high temperature themselves when the granite was intruded. Witness the widespread zones of passage between the two. The great coarseness of the matrix shows that the granite was long in crystallizing and in that process would naturally lose much heat to the surrounding rocks.

Thus the latter could not in the final stage of consolidation cause a serious differential cooling in the marginal part of the granitic magma. That there was some influence exerted upon the igneous rock is indisputable. Almost universally thin sections of the contact-zone exhibit a very marked granophyric intergrowth of the quartz and feldspar of the matrix. This micrographic development is quite independent of that noted as common about the phenocrysts, and is quantitatively much superior in value to the latter. The occurrence of the graphic structure in the matrix is usually restricted to the contact-zone of not more than a few inches or feet in width. It is noteworthy, however, that in parts of the Ashuelot area where there are evidences of some crushing, this structure is found in various parts of the coarse matrix, though far from a contact. It doubtless originated as a result of rearrangement during the period of stress which the rock has here undergone.

The origin of the foliation in the porphyritic granite.—It is now well established that gneisses may belong to three classes which in the words of Gregory[1] may be named metapyrigen-gneisses, clastic-gneisses, and fluxion-gneisses. The first kind is produced by the pressure-metamorphism of igneous rocks, the second by the complete alteration of sediments. The third division has its origin in molten rock-magmas which have undergone "fluxional movements anterior to complete consolidation in a mass not perfectly homogeneous."[2] The porphyritic granite of New Hampshire owes its foliated structure to the same cause as that of fluxion-gneisses. In short, this porphyritic gneiss is a porphyritic granite with a flow-structure. The parallelism among the constituents was assumed when the rock was not yet fully crystallized out and cannot thus be referred to any metamorphic result of mountain-building acting on an already solidified mass. It is a primary structure. Since this fact is not as yet demonstrated in what has been said, and since we are dealing with a great terrane characterized everywhere by this foliation which has been the subject of serious misapprehension among early investigators in the state, we shall go into some detail to establish this position.

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[1] Q. J. Geol. Soc., 1894, p. 266.

[2] T. G. BONNEY, Some Notes on Gneiss, Geol. Mag., 1894, p. 118. Cf. HILL and BONNEY, Q. J. Geol. Soc., 1892, p. 137.

It was not until the next generation after von Buch[1] described flow-structure in lavas that the phenomenon was studied with reference to the origin of gneisses. Scrope[2] in 1840 and Darwin[3] in 1844, closely followed by Naumann,[4] first laid emphasis on the truth that "dragging movements" on a cooling granitic magma may lead to the formation of gneiss. Since that time, a host of observations have confirmed their idea so completely that it is now possible to frame the most important criteria which ought to be applied to a problematical case, and, if satisfied, should enforce belief in the gneissic structure of that particular instance being of fluxional origin. It is proposed to consider briefly these criteria with respect to their validity and to their relation to our particular problem.

1. Since the fluxion-structure is due to differential stress, we should expect some parts of a mass, to display a greater excellence of the foliation than others. There will be zones of relatively rapid movement and zones of more static conditions; at least during the geological movement of final consolidation. Thus, we may expect to find transitions from trendless granite to well-foliated granite or gneiss.[5] We have already seen how abundantly this change is exemplified in all the areas of the porphyritic granite. Both of the State Surveys noted this relation between the massive and foliated phases.[6] The earlier one seized upon the former as indicating simply a granite, the second

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[1] Geognost. Beobacht. auf Reisen durch Deutschland und Italien, 1809, II, p. 209.

[2] Trans. Geol. Soc., 2d ser., II, p. 228.

[3] Geological Observations, etc., 1st ed., 1844, ch. iii.

[4] Neu. Jahrb., 1847, p. 297. Q. J. Geol. Soc., Notices of Memoirs, p. 1.

[5] MICHEL LÉVY, Bull. Soc. Geol. de France, 1878–9, p. 852. MCMAHON, The Gneissose-Granite of the Himalayas. Geol. Mag., 1887, p. 214. *Ibid.*, 1888, p. 63. HARKER and MARR, The Shap Granite, etc. Q. J. Geol. Soc., 1891, XLVII, p. 284 EMERSON, Bull. Geol. Soc. Am., I, 1890, p. 559.

[6] Note, Geol. of New Hampshire, Vol. II, p. 99.

survey regarded the non-foliated parts as fused parts of a series of altered sediments.

2. The parallel structure ought to be best assumed along the contact, because there the essential condition of an appropriate viscidity will be assumed within a zone which has a dominant trend. Where the interaction effects of more than two cooling surfaces meet, as they do in a mass of considerable breadth, there is a tendency towards the obliteration of parallelism induced in any one zone of chilling at a plane of contact. Convection currents will further complicate the flow-structure and to a greater extent in the hotter core of an intrusive mass than in the chilled zone. For these reasons parallelism among the constituent minerals should be most clearly exhibited along the boundaries where the structure-planes of the igneous mass will accord in direction with the plane of contact. The central area may either lose any incipient foliation or show sudden irregular changes of strike and dip of fluxional planes which do exist. In other words, wherever else it may appear, the fluxional structure is to be looked for chiefly at the margins.[1]

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[1] BRÖGGER (Die Silurischen Etagen 2 und 3; Kristiania, 1882, pp. 325, 326), describes the endomorphic zone of contact of his granitic and syenitic eruptives as possessing a parallel structure "wodurch gestreifte Gesteine, bisweilen wie echte krystallinische Schiefer aussehen. It is parallel to the irregular boundaries of the igneous rocks.

MCMAHON, Note on the Foliation of the Lizard Gabbro; Geol. Mag., 1887, p. 76.

BARROIS states that in the granulites of Morbihan the parallelism is most perfect when the contact-line is in the strike of the enclosing strata. In such parallel contacts, the granulite is apt to change to a "granulite porphyroïde, à grands éléments, alignés fluidalement." In "contacts perpendiculaires" the rock has an aplitic phase in which the crystalline constituents have regular geometric forms. He considers that such differences in the intruded granite depend on the country-rock as an agent chemically inactive but "diversement conducteur de la chaleur et de la pression." Sur les modifications endomorphes des massifs granulitiques du Morbihan; Comptes Rendus, CVI, 1888, p. 428.

GEIKIE, A., The History of Volcanic Action during the Tertiary Period in the British Isles; Trans. Roy. Soc. Edin., 1888, p. 37.

BARLOW, On the Contact of the Huronian and Laurentian Rocks North of Lake Huron, Am. Geol., VI, 1890, p. 22.

SMITH, W. H. C., Ann. Rep. Geo. Surv. Canada, 1890-1, map.

GREGORY, J. W., The Waldensian Gneisses and their Place in the Cottian

The reader will remember how often this principle was illustrated in our detailed account of contact-phenomena. It undoubtedly explained the greater perfection of the foliation in the long and narrow Winnipiseogee area than that in the broadly eliptical Ashuelot area or Main area. At the Bennington reservoir in the large size of the feldspar phenocrysts and their definite orientation with respect to the adjacent contact we have a good example of what characterizes the endomorphic zone of the Main area throughout the eastern contact as mapped. Within the zone the structure is much less determinate. Again, on Sandwich Mountain the porphyritic granite in and about the "permeation-area" described above, is largely granitic with the exception of those parts which display the fluxional habit about the horses. We are not without suggestion that the sudden changes of dip and strike within the cores of the igneous masses are largely the result of convection acting with massive pressure in the still viscid rock-body. Two miles from Weirs, on the highway to Meredith village, several outcrops appear in a clear field some three hundred yards to the right of the road. At one of these, a well-marked anticlinal arrangement can be observed in typical porphyritic granite. This structure is not part of a general system of parallel folds, nor of folds with any recognizable relation to the behavior of solid rock acted upon by lateral force. It is rather to be correlated with the irregular flow-structure assumed in the internal parts of many rhyolites; the well-known "felsites" of eastern Massachusetts furnish a good example.[1]

3. An analogous appearance will tend to characterize the margins between the intrusive rock and any foreign bodies which

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Sequence; Q. J. Geol. Soc., 1894, p. 249. On page 265 the author says of the foliation in these Alpine gneisses that it is "a contact-fluxion, and has no connection with the dynamo-metamorphism of the district. This marginal orientation also occurs on a microscopic scale. Mr. C. L. Whittle has described good examples in the contacts of the Connecticut Triassic lavas.

BONNEY, T. G., Some Notes on Gneiss; Geol. Mag., 1894, p. 118.

[1] Cf. MEHNER, "Fluctuationstructur" described in certain of "die schiefrigen Porphyren" of Westphalia; Tsch. Mitth., 1877, p. 177.

are caught up from the surrounding terranes.[1] In many cases, however, it is due not only to differential cooling, but to the pulling of the horses along in the direction of the migrating viscid magna. Such is the case with the examples of the circumferential arrangement of feldspars noted on Sandwich Mountain, on Saddle Hill, and in the Fitzwilliam area, and elsewhere.

4. Many observers have described the orientation of horses parallel to the margins of contact in cases where the inclusions have distinct elongated form.[2] The latter condition is usually furnished in the case of fragments derived from a country-rock with plane-parallel-structure. Consequently, we can understand this very general marginal arrangement described in all of the principal areas.[3]

5. The greater the heterogeneity among the constituents of the igneous body at the time of proximate consolidation, the more pronounced will be the flow-structure.[4] As suggested by Bonney,[1] horses may be melted up and thus give local variations in the mineralogical constitution of the igneous body. "Banding" is sometimes produced by the imperfect mixing of more

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[1] LAWSON, The Geology of the Rainy Lake Region; Ann. Rep. Geol. Surv. Canada, 1887-8, F, 137-138. BARLOW, op. cit., p. 29. DAKYNS and TEALL, On the Plutonic Rocks of Garabal Hill and Meall Breac; Q. J. Geol. Soc., 1892, p. 106. KOTO, B., The Archæan Formation of the Abukuma Plateau; Jour. Coll. Sci. Imp. Univ., Tokio, 1893, p. 288. GREGORY, Q. J. Geol. Soc. 1894, p. 242.

[2] DUROCHER, Mém. de la Soc. Géol. de France, 2e sér., t. VI. See his descriptions of several gneiss-granite contacts in Scandinavia; LEHMANN, Untersuchungen über die Entstehung der altkryst. Schiefergesteine. Bonn, 1884, pp. 16, 21; GEIKIE, A., op. cit., p. 39; GRANT, U. S., Field observations on certain granitic areas in northeastern Minnesota; 20th Ann. Rep. Minn. Surv., 1891, p. 40.

[3] Cf. EMERSON, Bull. Geol. Soc. Am., I, 1890, p. 559.

[4] Geol. Mag., 1894, p. 119. Cf. BONNEY, *ibid.*, 1894, p. 118. C. CHELIUS has recently described a stage leading to the complete fusion of enclosed masses, which is of interest. In this case granite cuts diorite and includes so many lenses of the latter in parallel arrangement as to simulate a "grobflaseriger gneiss." Notizbl. d. Ver. f. Erdk. Darmstadt, IV, Folge, 14 Heft, 3-8, 1893. Ref. in Neu Jahrb., 1895, p. 72.

J. J. SEDERHOLM speaks of "Schlieren" rich in mica and garnets in the "druckschieferiger Granit" of Finland. They are taken to represent remnants of schist-inclusions which have been dynamically metamorphosed. Om Börggrunden i Södra Finland, 1893. Ref. in Neu. Jahrb., 1895, p. 335.

than one phase of a magma.[1] It is conceivable that it might be locally brought about by the pulling out of basic segregations in a plutonic rock by mechanical force operating during or after complete consolidation.

On the road along the north shore of Wickwas pond a striking phase of the porphyritic granite was found which had been discovered before but never in such perfect development. It forms a strongly schistose mass a few inches thick which lies parallel to the foliation of the normal rock. Composed largely of brown biotite with here and there a large feldspar phenocryst, it is very different in appearance. With the biotite large apatites and considerable masses of titanite and magnetite make up the groundmass. This band had much the appearance of a shear-zone, like that described in the crystallines of the Malvern Hills.[2] But the microscope discloses no strong evidences of crushing in the feldspars which are clearly original or primary in their nature. Now there are plenty of cases on record where biotite segregations in granitic rocks grow to large size. Those at Graniteville, Missouri, vary from a few inches to five feet or more in diameter.[3] It may be that this and similar local bands in the rock in question are due to the tailing out of such segregations before the final solidification of the whole rock had set in. The resulting bands would thus be parallel to neighboring structure-planes and take their place as primary elements in a fluxional mass.

But the most favorable chance for the exhibition of a parallel structure over large areas would be given in cases where there is more than one generation of minerals; *i. e.*, in porphyritic rocks. Such, indeed, has been the character of most of the plutonic rocks where extensive flow-structure has been described. The large size of the phenocrysts of the porphyritic granite is one of the chief conditions leading to this peculiar and widespread foliation. Possessed of large growth before the final magmatic crystallization set in, each feldspar phenocryst was, as it were, of the nature of a foreign body embedded in the matrix. Thus, it would behave in the same manner as the truly exotic inclusion and a conspicuous alignment would result. It was observed in the field that, as a rule, the greater the dimensions of the phenocrysts, the more clearly was the structure displayed.

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[1] HARKER and MARR, Q. J. Geol. Soc., 1891, p. 283; A. GEIKIE and TEALL, *ibid.*, 1894, p. 656.

[2] Q. J. Geol. Soc., 1889, p. 477.

[3] Geol. Surv. Missouri, Ann. Rep., VIII, 1894, p. 154.

It is clear that the porphyritic granite with its elongate feldspar phenocrysts abundantly fulfills this criterion. In fact, the study of it suggests that plutonic rocks would more generally show a flow-structure were their constituents more varied in shape and relative size from the usual forms.

Quite rarely a broad banding is observable which is the result of the juxtaposition of layers containing different proportions of the phenocrysts.[1]

6. The negative criterion is valuable and in this New Hampshire case is most conclusive. If it can be shown that mountain-building could not induce the parallel structure in any secondary fashion, *i. e.*, by the pressure-metamorphism of consolidated, igneous or sedimentary rocks, we can fairly assume that the only other recognized cause has been operative. The evidence necessary therefore is threefold.

First, it may be derived from the study of foreign inclusions. The schistosity of the horses in all the observed localities where they occur within the porphyritic granite was evidently produced before the existence of that rock in its present state of crystallization. In practically all cases where comparison was possible, the excellence of this structure in any one inclusion was reflected in its parent-terrane. As the one varied from massive to schistose with a high degree of fissility, so did the other. Now the perfection of the schistosity was found to be irrespective of the attitude of the horses, *i. e.*, whether they were in parallel arrangement or not. Callaway used the correlative of this principle as an aid in determining the nature of the foliated granites of Northern Donegal.[2] He finds in them inclusions of massive diorites. His conclusion is, that on any theory of a mechanical origin for the foliation, it would be "hard to explain the escape of the diorite inclusions from the same influence." But if the intrusion of the porphyritic granite followed the period of plication and metamorphism, we should expect it to follow commonly the structural planes of the preëxisting schists.[1] Again referring to our detailed description of contacts in the three large areas, it will be seen how commonly this is the case. The intrusions are batholitic in their nature. They entered the overlying rocks by melting[2] their way through the axial zones of flexures. It is for this reason that the general distribution of these granite bodies is along the strike of terranes in this part of New Hampshire. The equivalence of strike and dip in the region in the narrow part of the "Fish-hook" north of Squam Lake between the foliated igneous rock and the adjacent schists is especially conspicuous.[3] Such pronounced apparent conformity is probably owing to an exchanging of the usual batholitic form of intrusion for a sill or sheet-form.

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[1] Cf. G. H. WILLIAMS, Bull. U. S. Geol. Surv., No. 28, p. 26.

[2] READE, Origin of Mountain Ranges, p. 139.

Secondly, the study of apophyses will be of much consequence. If we there see parallelism of the minerals composing the intruded tongue to its walls, no matter what the compass-direction of the apophysis may be, it is evident that the structure cannot be referred to mechanical deformation applied after the cooling of the whole intrusive mass.[4] Scheerer early described an occurrence of the opposite of this.[1] He determined that the red gneiss of the Erzgebirge is plainly eruptive into the gray gneiss. The apophyses of the former have a distinct parallel arrangement among the constituents. It is, however, not parallel to the walls, but inclined to them. He, hence, concludes that it is due to pressure exerted after the consolidation of the ancient granite.[2] That the apophyses should be as coarsely porphyritic as the main body, is of itself a strong suggestion of the exotic origin of the latter.[3] As we have seen, such is the case with the porphyritic granite, and in many instances, as on Saddle Hill, on Sandwich Mountain, in the Greenfield dike, and at Fitzwilliam, the apophyses have a more or less well-developed foliation, parallel to the walls and transverse to the structure-planes of the schists.

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[1] See GÜMBEL, op. cit., p. 522, 523, 524. He describes "Lagergranite" intruded into various schists. It is rather remarkable that his "Krystallgranit" of Bavaria does not possess a decided flow-structure. The rock is very similar to the porphyritic granite otherwise. Cf. also LAWSON, Ann. Rep. Geol. Surv. Canada, 1885, CC, p. 73, LEHMANN, op. cit., pp. 10, 23; WILLIAMS, G. H., Proc. A. A. A. S., 1887, XXXVI; Sect. E, p. 225; CALLAWAY, Geol. Mag., 1887, p. 354; LAWSON, Ann. Rep. Geol. Surv. Canada, 1887–8, F, p. 32; DANZIG, Mitth. aus dem Min. Inst. der Univ. Keil Bd. I. heft 1, 1888, p. 66; BARLOW, Am. Geol., VI, 1890, pp. 21–22; HARKER and MARR, op. cit., p. 284; ADAMS, Jour. of Geol., 1893, p. 334: SMITH W. H. C., Bull. Geol. Soc. Am., 1893, p. 338.

[2] From the author's previous statements there is no evidence that melting took place in connection with these intrusions. [ED.

[3] See the map of Hunter's Island by Mr. W. H. C. SMITH, which shows a very remarkable parallelism of the foliation in his "granite gneiss" with the strike of the enclosing schists. Ann. Rep. Geol. Surv. Canada, 1890–1.

[4] LAWSON, The Geology of the Lake of the Woods Region; Ann. Rep. Geol.

Lastly, while the porphyritic granite shows in certain areas evidence of strain, there is none of that very intense crushing which might be looked for if the foliation were of a mountain-built origin.[4] The signs of pressure in some of the phenocrysts may be due to the shearing set up among them in the tough, but still viscid magma, just on the instant of final consolidation. At the south end of the Ashuelot area we have the most schistose phase of the rock. It has evidently been squeezed to some extent. It is crumpled and even changed to an augen-gneiss whose lenticular feldspars represent the idiomorphic phenocrysts of the original rock.[5] Small faults of a half foot throw were observed in the Winnipiseogee area, just

Surv. Canada, 1885, CC. p. 83, DANZIG, Ueber die eruptive Natur gewisser Gneisse sowie des Granulits im sächsischen Mittelgebirge; Mitth. aus dem min. Inst. der Univ. Kiel. Bd. I, Heft 1, 1888, p. 67. REUSCH, Neu. Jahrb., Beil. Bd, V., Heft 1. 1887, p. 57.

[1] Die Gneisse des sächsischen Erzgebirge; Zeit. d. d. geol. Ges., 1862, pp. 122–123.

[2] Credner attempted to prove that the red gneiss of the Erzgebirge is of sedimentary origin and not eruptive, as held by von Cotta, Scheerer, Stelzner, and others. Zeit. d. d. geol. Ges., 1877, p. 757.

[3] Cf. MCMAHON, Geol. Mag., 1888, p. 63; Q. J. Geol. Soc., 1893, p. 357.

[4] Cf. LAWSON, The Geology of the Rainy Lake Region, Ann. Rep. Geol. Surv. Canada, 1887–8, F, pp. 137–138.

[5] Cf. HAWES, Geol. of N. H., III, p. 214.

north of Wickwas pond. But there is nothing to indicate that any batholite as a whole has undergone any such enormous stresses as have affected the anorthosite of Canada, the protogine of the Alps, or even the gneisses of the Malvern hills.[1] Under the microscope the New Hampshire rock always shows that the essential minerals crystallized in place and that they have only been affected, except locality, by moderate pressures.

From the complete satisfaction of these several criteria one cannot escape the conviction that the foliation of the porphyritic granite has nothing to do with stratification, and has not been caused by the alignment of the constituents in a time of pressure metamorphism acting on a consolidated rock.

The significance of the uniformity of the porphyritic granite and its wide geological distribution.— One of the most striking characteristics of the porphyritic granite is the lithological sameness which pertains to it to a great degree throughout all the areas examined. This property is retained irrespectively of the nature of the rock-terranes which it invades. From the many examples of endomorphic changes induced in plutonic rocks by the melting up of foreign inclusions, we have selected a few which are described in the annexed footnote.[2] In view of this principle, it may be asked, why does the porphyritic granite not show more variations of mineral content ? To this question we have no conclusive answer. It is possible that the rock which now fills the areas of the porphyritic granite was in general not at a temperature high enough to cause vigorous melting up of the walls, and that the great spaces in the earth-crust now filled by the granite were opened during the passage upward of earlier and hotter parts of the same magna. However this may be, the difficulty remains just as great for any theory of a metamorphic origin for the granite. It is impossible to believe that a rock with such continuity of like characters should have resulted from the alteration of the stratified or schistose rocks in the accompanying terranes of New Hampshire. Although the determinations of relative age among these terranes are as yet necessarily imperfect, we know that the porphyritic granite is in contact with rocks of many different horizons and of very variable composition. From this fact, it seems reasonable to conclude that the porphyritic granite is an exotic eruptive, finding its source of supply elsewhere than in any metamorphic center in immediate connection with the encircling schists. McMahon lays considerable stress on this idea in his argument for an eruptive origin of the Himalayan granites.[1] Lawson, in his study of the Laurentian gneisses, and Barlow, in a similar problem among the ancient rocks north of Lake Huron,[2] refer their "irruptive" masses to a fusion of the granitic floor on which the post-Laurentian rocks were laid. The New Hampshire rock is thus, in respect to its origin, more closely allied to the Himalayan granite than to the gneiss of the Canadian Laurentian.

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[1] CALLAWAY, Q. J. Geol. Soc., 1887, p. 525.

[2] Michael Lévy finds that by an endogenous action granulite cutting diabases and diorites is enriched in plagioclase at the contact (Bull. de la Soc. Géol. de France 1882–3, p. 296). Lehmann states that where the granitite of Döbeln is intruded into biotite-bearing rock, it is practically unchanged, but when it cuts in contact with sericitic schists, siricite is an important constituent (Untersuch. über Ent. d. altkryst. Schiefergesteine, Bonn, 1884, p. 19). Again, on classic ground, Lawson determines his Rainy Lake eruptive rock to be a quartzose biotite-granite gneiss where it comes in contact with quartz porphyries, yet the same rock-body cutting the more basic hornblende schists becomes a hornblende syenite with little quartz (Ann. Rep. Geol. Surv. Canada, 1887–8, F, 31). In one of the great batholites of western Massachusetts, Emerson notes three phasal differentiations, a heavy hornblende granite, a hornblende granitite, and a granite proper, all of which he attributes to the melting up of three various sorts of crystalline schists respectively (Bull. Geol. Soc. Am., I, 1890, p. 559). A similar affection of a porphyritic granite by a hornblendic country-rock is found in Chor Mountain, India (Geology of India, 2d ed., by Oldham; Strat. and Struc., p. 43); while quite recently Harker notes a good case of a relatively basic modification of granophyre at its junction with gabbro, and ascribes it mainly to an incorporation of re-fused gabbro (Q. J. Geol. Soc., 1895, p. 134).

Coarse veins cutting porphyritic granite.— McMahon and others describe plutonic eruptives intersected by dikes and veins of very similar material to that of which their hosts are composed. Besides the usual evidences of an eruptive origin for the Dalhousie gneissose granite of northern India, McMahon adds a criterion which is certainly without the weight of its associates, but which has been recently used more than once. He states that "the granite contains veins similar to those caused by shrinkage on cooling in granites of admittedly eruptive origin."[1] Emerson makes the principle more definite. Speaking of the largest granitic intrusion in Massachusetts west of the Connecticut River, he says: "The great mass is cut everywhere by a very great number of dikes of a coarse muscovite-granite, which seem to represent later intrusions of the central portions of the mass into shrinkage cracks in the already cooled peripheral portions, and thus to represent more truly its original composition."[2] This seems to be the best interpretation of those coarse dikes cutting the porphyritic granite composed of large individuals of the same minerals that make up that rock. They occur everywhere, though there is a concentration of them along the boundaries. With them are often associated the pegmatite veins of variable mineralogical constitution of aqueo-igneous origin and apparently without direct connection with the underlying magma.[3] On Gun Mountain, on Bear Hill, on the road following the valley of Rixford brook, and in the eastern area near New Hampton Centre, dikelike bodies of the former kind transect the porphyritic granite. Such localities suggest that in this respect also the main granitic mass is eruptive.

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[1] Geol. Mag., 1887, p. 216 ; Rec. Geol. Surv. India, XVIII, 1885, p. 106.

[2] Bull. Geol. Soc. Am., IV, 1893, p. 331.

The age of the porphyritic granite.—We have seen that the porphyritic granite intrusions were posterior to the stress-period during which the chief metamorphism of the New Hampshire rocks was brought about. The position of the axis of flexure determined largely the shape of the different important areas. Each one is batholitic in its nature. Since the eruptions ceased, no considerable deformation has occurred. In this, all the areas are alike, and from other facts, too, they were without much doubt essentially contemporaneous.

Now, the geologically highest fossiliferous zone within the mountain-built strata is the well-known one at Bernardston, Mass., some seven miles to the southwest of the Ashuelot area. The first studies of the organic forms enclosed in the limestones at this place referred them to the Helderberg or lower Devonian. More recent determinations now fix the age of the limestones as being at the Hamilton-Chemung stage of the Upper Devonian. They are folded up with quartzites and mica- and hornblende-schists which are intensely metamorphic. The careful field work of Professor Emerson and of the late Professor Dana has shown that these metamorphic rocks are a part of the same terrane which throughout this paper and the survey reports of the New Hampshire survey has been called the "Coös group." As early as 1873, Dana concluded that "the Bernardston, South Vernon, and Northfield beds being of Helderberg age, the Coös group, which is but the northern continuation of the same series, is, if correctly traced out, also Helderberg."[1] Professor C. H. Hitchcock adopted this view, although he disagreed with Dana as to the stratigraphic order of the rocks adjacent to the limestones.[2] Professor Emerson followed with the publication of his results after a painstaking lithological and structural study of the whole area. In this paper he most emphatically states his conviction and advances new proof that Dana's position was the correct one.[3] Two years later Dana reiterated his opinion,[4] and in his last and greatest work clearly shows that it persisted for the rest of his life.[5] Professor Emerson is inclined to place the faults and folds which dislocate the Bernardston rocks in Carboniferous or post-Carboniferous time. He attains this result by combining his observations at Bernardston with those in the more richly fossiliferous localities farther south, in the state of Massachusetts. Thus we may conclude that the porphyritic granite is probably a post-Carboniferous intrusive and certainly younger than the upper Devonian at any rate.

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[1] Geol. Mag., 1887, p. 216.

[2] Bull. Geol. Soc. Am., 1890, p. 559. Cf. HARKER and MARR, Q. J. Geol. Soc., 1891, p. 284.

[3] Cf. BARLOW, Am. Geol., VI, 1890, p. 29.

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[1] Am. Jour. Sci. (3), Vol. VI, 1873, p. 349.

[2] Am. Jour. Sci. (3), Vol. XIV, 1877, p. 380.

[3] Am. Jour. Sci. (3), Vol. XL, 1890, pp. 263 and 366; especially p. 366.

[4] *Ibid.* (3), Vol. XLIII, 1892, p. 456.

[5] Manual of Geology, pp. 310, 325.

Posterior to the schists, to the so-called protogines, and to other old eruptives on the one hand, the porphyritic granite is, of course, older than the aplitic and lamprophyric dikes which intersect it. It is also older than the Fitzwilliam granite, the hornblende granite stock of Mount Whiteface, the Franconia breccia,[1] and probably older than the complex stocks of the Waterville area. It is impossible with the facts now in hand to go further in fixing an epoch for these great intrusions. The porphyritic granite may even belong to the Tertiary.

SUMMARY.

Briefly stated, the chief conclusions which have been arrived at in the foregoing pages, are as follows :

1. The so-called "porphyritic gneiss" of New Hampshire is at least in the three most important areas, an eruptive porphyritic granite with a common tendency to develop planes of foliation.

It is not to be regarded as indigenous, that is, as the pure fused product of the surrounding formations — a deep-seated exotic origin must be posited for the granite. The evidences for an igneous instrusive origin include the composition and structure of the rock itself, the study of field-relations, the fluxional nature of the foliation, the uniformity of the rock in all its extent and the prevalence of secondary dikes and veins of injection apparently derived from the same magma. Besides these positive facts, there are also those embodied in what may be termed negative evidence. It includes all those observations that have been made in which the peculiarities of the region and of each intrusion will explain why some of the usual criteria of eruptive origins are not perfectly fulfilled. Chief among them is the fact of small certain and undoubted metamorphic effects at contacts — one which we have seen can be readily understood from the characters of the invaded rocks. Lastly, the contacts at first sight equivocal prove to be intrusive contacts on comparative evidence. The existence of zones of passage between the porphyritic granite and the schists with which it comes in contact is a fairly common phenomenon in the case of stocks of plainly eruptive material. Such transitions then form no inherent objection to a similar origin in this instance.

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[1] Geol. of N. H., Vol. II, p. 257.

2. The intrusions necessarily took place under great depth of strata. The latter were elevated by the last great period of White Mountain flexure and were practically holocrystalline products of the consequent metamorphism before the porphyritic granite was intruded. The subsequent disturbance of the greatest interest to us in this connection is that which caused the porphyritic granite to assume the parallel structure of flowage under differential stress analogous to that of the Himalayan and Alpine central granites. Since that time, the force operating on the terranes has been relatively slight. It has not sufficed to rub out completely, in any part, this initial structure of the porphyritic granite.

3. The molten rock entered the overlying schists in an irregular fashion but in general followed the regional line of strike of the White Mountain district.

4. Various considerations lead us to believe that the three areas of porphyritic granite described are virtually contemporaneous. They are, in every case, post-Devonian in age, — how much younger is unknown. Not being a basal formation, the terrane loses much of its value in an elaboration of the stratigraphic sequence and a reconstruction of the New Hampshire geological scale is necessary.

5. The porphyritic granite adds its testimony to the value of the opinion recently formulated among geologists that a highly important class of gneisses owes its parallel structure to fluxional movement. And it has the other general kind of interest in exemplifying the truth of Barrois' prophecy "que les terrains paléozoiques sont destinés à s'étendre de plus en plus sur les cartes géologiques aux depens des terrains primitifs."

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